TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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COMPARATIVE PERFORMANCE OBTAINED WITH XF7C-1 AIRPLANE USING SEVERAL DIFFERENT ENGINE COWLINGS

By Oscar W. Schey, Ernest Johnson, and Melvin N. Gough
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Summary

Although the research that has been conducted on the cowling of radial air-cooled engines has resulted in the improvement of the performance of airplanes equipped with this type of engine, it has introduced other problems, such as visibility, accessibility, cooling, and the necessary modifications of airplanes now in service. For the purpose of further investigating these problems, the National Advisory Committee for Aeronautics conducted the tests herein reported.

An XF7C-1 airplane, equipped with service cowling and with narrow ring, wide ring and exhaust collector ring cowlings over the service cowling, was used. For these four cowling conditions the rate of climb and high-speed performance were determined, the cylinder temperatures were measured, and pictures to show visibility were taken.

The level flight performance obtained with an engine speed of 1900 r.p.m. for the service type, the narrow ring, the wide ring, and the exhaust collector ring, was 144.4, 146.6, 152.8, and 155 m.p.h., respectively. The rate of climb was

practically the same with each of the cowlings tested. The visibility was not materially impaired by the use of the wide or narrow ring cowlings. No increase in cylinder temperatures was obtained with the wide ring cowling. With the narrow ring and exhaust collector ring cowlings there was an increase in temperature. However, as this increase was not large it did not affect the performance of the engine. The use of an exhaust collector ring incorporated in the cowling is practical where the problem of visibility does not enter.

Introduction

Widespread interest in the cowling of radial air-cooled engines has prevailed during the last few years, and the research that has been conducted on cowlings has resulted in a large improvement in the performance of airplanes equipped with this type of engine. Practically every manufacturer of radial air-cooled engines and of airplanes using such engines is interested in obtaining cowlings which will reduce the drag without affecting the cooling efficiency, visibility, or accessibility, and which can be adapted without many changes to airplanes now in service.

In view of this and of previous flight and wind-tunnel tests (References 1, 2, and 3), which conclusively demonstrated the practibility of using cowlings of the N.A.C.A. type, the Committee believed that further work should be done on the cowling of radial engines. The object of these tests was the modification of the N.A.C.A. cowling or the design of a cowling that would embody as many as possible of the desirable characteristics in which manufacturers are interested.

The tests herein reported were conducted on an XF7C-1 airplane. The high speed, rate of climb, and cylinder temperatures were obtained with the service cowling, with two plain ring cowlings, and with an exhaust collector ring cowling. The rate of climb was obtained for altitudes from 0 to 10,000 feet, and the high-speed performance was determined at sea level. Photographs were taken to show the visibility with each cowling.

This work was done at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics.

Description and Method of Test

The XF7C-1 airplane used in these cowling tests was a single-seat shipboard fighter built for the Navy by the Curtiss Aeroplane and Motor Company, Inc. (Figs. 1 and 2). It was powered with a Pratt and Whitney "Wasp" engine rated at 410 hp at 1900 r.p.m. It differed from the original XF7C-1 airplane, for that airplane was crashed, and when it was rebuilt F7C-1 wings were used. These wings have an area of 275 sq.ft., as compared with 242 sq.ft. for the original XF7C-1 wings. Since all of the data were used on a comparative basis, it is a matter of little concern just what airplane this really was.

The weight of the airplane fully serviced, with service cowling, pilot, parachute, and instruments, was 3024 pounds at take-off. The instruments and battery composed about 90 pounds of the weight and were located in the fuselage aft of the pilot's cockpit. The static balance of the airplane was thus changed, but it remained within the range of the stabilizer adjustment and was the same throughout the tests.

An aluminum alloy adjustable-blade propeller was used in these tests (Navy drawing No. 3792). The diameter of this propeller had been cut from 10 ft. to 9 ft. Tests recently conducted on this propeller in the propeller research tunnel showed that the cutting down of propeller did not appreciably affect its efficiency (Reference 4).

The four different cowlings used in these tests were the service cowling, the wide ring, the narrow ring, and the exhaust collector ring. In all of these tests no change whatever was made to the service type cowling, since the ring cowlings were mounted over the service cowling. All of the cowlings were constructed of 1/16 inch sheet aluminum braced with steel tubing and supported at the engine by sheet-iron brackets attached to the exhaust pipe studs. The general lines of the cowlings are shown in Figure 3.

Figures 1 and 2 show the airplane with the service cowling. This cowling is of conventional design and is fitted with shutters at the nose and louvers on the side at the rear of the engine.

The next cowling tested was a modification of the original N.A.C.A. outer cowling in that the shape of the nose was changed to improve the visibility. This cowling is designated as the wide ring cowling (Figs. 4, 5, and 6). It is constructed with a 3/4 inch tube at its leading edge to which are attached two sheets of aluminum forming the inner and outer shell or line of the cowling. It is 21-1/4 inches wide and resembles an airfoil in cross section. The diameter at the nose is 1-1/4 inches smaller than that at the rear and is 1/2 inch larger than the maximum diameter of the engine. Thus, when the cowling is in place the chord of its section is nearly parallel to the thrust line of the engine, being at a small negative angle. The supporting brackets are so made as to permit the cowling to be used in various positions fore and aft. In the forward position, as used in these tests, the leading edge was 9-1/4 inches forward of the center line of the cylinders. This cowling with its supporting brackets increased the weight of the airplane 40 pounds.

The narrow ring cowling is shown in Figures 7, 8, and 9. This cowling was also designed to improve the visibility. It is 9 inches wide and has a Clark Y airfoil section. This cowling was centered over the center line of the engine. It increased the weight of the airplane 21 pounds.

The exhaust collector ring cowling (Figs. 10 and 11) was made with approximately the same chord as the wide ring, but with a thicker section, as shown in Figure 3. This thicker section considerably impaired the visibility, but it made possible the incorporation of an exhaust collector ring. The exhaust ring portion of the cowling was made of 3/64 inch sheet iron and was so constructed that the exhaust gases discharge from its trailing edge on the lower semicircle only. This cowling weighed 106-1/2 pounds, but it increased the weight of the airplane only 87-1/2 pounds, since the service exhaust stacks of 19 pounds were no longer necessary.

The readings of all instruments were recorded automatically. A recording altimeter and air-speed meter unit gave a continuous photographic record, while a motion picture camera gave an intermittent record of the readings of several instruments mounted in an automatic observer. These included two pyrometers, which were connected in rotation with thermocouples located at 18 points on the engine cylinder heads and barrels, electrical resistance thermometers giving the temperature of the atmosphere and of the thermocouple cold junctions, an indicating air-speed meter, and a tachometer.

The performance of the airplane in level flight and climb was determined with each cowling. The propeller pitch setting was changed when necessary to keep the maximum engine speed at approximately 1950 r.p.m. However, the same pitch settings were used in climb as were used in level flight. The following schedule of flight tests was carried out for each cowling:

(1) A full throttle level flight for 15 minutes at 1500 feet was made. This was more than ample time for engine and oil temperatures to become constant.

(2) A level flight was made at about 30 feet altitude over a measured course, making two pairs of runs with and against the wind for each of four throttle settings. One of these runs was at full throttle, while the others were at various throttle settings so as to cover the range of engine speeds used in flight. Care was taken to start each run well outside the limits of the course, so that all conditions would be constant when the start of the course was passed. The time was taken by the pilot with a stop watch.

(3) A full throttle 10-minute climb at the air speed giving the best rate of climb was made. The performance data in climb were worked up according to the Lesley method given in N.A.C.A. Technical Report No. 216 (Reference 5).

Pictures were taken from the cockpit to show the visibility with each cowling. By removing the windshield and placing the camera in approximately the same position as the pilot would occupy when seated in the middle of the cockpit and looking straight ahead, pictures of visibility could be obtained. The pictures were taken of cowlings with the airplane in flying positions.

Results and Discussion

The results of this investigation are presented in the form of curves, tables, and pictures. The curves in Figure 12 show the relation between engine speed and air speed for the service cowling, and for each of the other three cowlings tested. It is interesting to note that each of the modifications tried resulted in a reduction in drag, as shown by the increased air speed at any given engine speed. Although this improvement, as could be expected, was largest for the high air speeds, it nevertheless amounted to a substantial increase for all air speeds throughout the range investigated. The curves also show that the wide ring with the thick section gave the largest improvement.

During these tests the propeller pitch setting was changed for the purpose of keeping the maximum engine speed at approximately 1950 r.p.m. For the tests with the service cowling and the narrow ring cowling a propeller pitch setting of 19-1/2 degrees at the 42-inch radius was used, which gave maximum engine speeds of approximately 1935 and 1945 r.p.m., respectively. For the tests with the wide ring cowling and the exhaust collector ring cowling a propeller pitch setting of 20-1/2 degrees was used, which gave maximum engine speeds of 1950 and 2000 r.p.m., respectively. The maximum permissible engine speed of 1950 r.p.m. was thus exceeded by 50 r.p.m. for high-speed tests on the exhaust collector ring cowling.

The air speeds obtained at an engine speed of 1935 r.p.m., with the service type cowling, the narrow ring, the wide ring, and the exhaust collector ring, were 147.4, 149.8, 156.4, and 158.5 m.p.h., respectively. These results show that even with an engine speed as high as 1935 r.p.m. an improvement of only 2.4 m.p.h. was obtained with the narrow ring. By using a wide ring of thin section the air speed was increased 9 m.p.h. at this engine speed, but by using a wide ring of thick section and by careful fairing of entry and enclosing of rocker arm boxes within the cowling section, an increase in speed of 11.1 m.p.h. was obtained, as shown by the tests with the exhaust collector ring cowling.

The time-altitude and rate-of-climb curves are shown in Figure 13. The difference in climb obtained with each of the four cowlings tested was so small that the same rate-of-climb curve is representative of each condition. It should, however, be kept in mind that the flights with the service type and the narrow ring cowling were made with a pitch setting of 19-1/2 degrees, while those with the wide ring and the exhaust collector ring cowling were made with a pitch setting of 20-1/2 degrees.

There has been some discussion as to how the rate of climb would be affected by the use of N.A.C.A. cowling or modifications of this cowling. One investigator reports that a lower rate of climb was obtained with the N.A.C.A. cowling than with the service type, even though the high-speed performance was improved.

This is not impossible in view of the fact that the pitch setting which is best for high-speed tests may not be best in climb. However, if the pitch setting was changed so that the best setting was used both in climb and in level flight, it does not seem possible that the rate of climb could be reduced with the low-drag cowling.

For the high-speed tests the engine speed was limited to approximately 1950 r.p.m. by using the proper propeller pitch setting. In the climb tests, the air speed giving the maximum rate of climb, at the same pitch setting as employed in the high-speed tests, was used. The rate of climb, however, was not as good as could have been obtained if a pitch setting which would allow the engine to turn faster had been used.

Figure 14 shows how the visibility is affected by the use of the various cowlings. These pictures are self-explanatory. It will be noted that the exhaust collector ring cowling leaves only a small unobstructed field between the engine cylinders, while both the narrow ring and the wide ring are almost equal to the service cowling from a visibility standpoint.

The air speeds at engine speeds of 1500, 1600, 1700, 1800, and 1900 r.p.m., and the maximum, as shown in Figure 12, have been tabulated in Table I.

The cylinder head and barrel temperatures at seven representative points are given in Table II. These temperatures are the maximum readings recorded at any time during the full throttle climbs or level runs at 1500 feet. Apparently the wide ring cowling in the forward position does not cause any higher engine temperatures than the service cowling alone; however, in the rear position the temperatures are slightly higher. Both the narrow ring and the exhaust collector ring raise the engine temperatures, but not above what is regarded as a suitable range for the safe operation of the engine.

The flight test data obtained in climb on each of four cowlings tested are given in Table III. Calibration corrections have been applied to all instrument reading so that these data should be accurate to within ±2 per cent.

The stability characteristics of the airplane were impaired by the use of the cowlings. The airplane was practically neutrally stable as it was flown with the service type cowling, but it became longitudinally unstable when any of the outer cowlings were used. The instability increased as the width of the cowling was increased, but at no time was the airplane difficult to control. The cause and nature of the instability is a problem for future study.

In addition to the advantage of improved visibility, the modified cowlings have other advantages over the original N.A.C.A. cowling, such as accessibility and ease of mounting on airplanes now in service. However, good judgment must be exercised in the adding of cowlings to airplanes already in service, for the shape of the nose of the airplane may considerably influence the results obtained.

The principal object of the cowling is to reduce the air disturbance and to give the air leaving the cylinders a smooth flow so that it will follow closely along the fuselage. The results obtained in these cowling tests must not be interpreted as being obtainable on all airplanes, even though they have very nearly the same speed. They show the gain with this particular fuselage and nose combination.

Other tests now in progress, the results of which will be published later, using the same airplane but with different fuselage and nose shapes, show the effect of shape of nose and fuselage on the performance to be obtained with cowlings. Thus, an outer cowling which gives good performance with one airplane may not give as good performance on another airplane with a different shaped nose. The narrow ring cowling is much more sensitive to the shape of the nose and fuselage than the wide ring cowlings.

Conclusions

The results of these tests indicate that the use of the narrow ring type cowling as designed for the particular installation studied, gives a small increase in high-speed performance over the service type of cowling. Another narrow ring type cowling has been constructed by the Committee which permits of the changing of the angle of attack through a range of 14 degrees. This type of cowling will be tested on the same airplane.

The use of a wide ring or an exhaust collector ring cowling resulted in a large increase in speed. The service cowling, the narrow ring, the wide ring, and the exhaust collector ring cowlings, at an engine speed of 1900 r.p.m., gave air speeds of 144.4, 146.6, 152.8, and 155 m.p.h., respectively.

The low drag cowling has practically no effect on the rate of climb.

The narrow ring and the wide ring cowlings do not materially impair the visibility.

The incorporation of an exhaust collector ring in the cowling is practical where the question of visibility does not enter.

With the wide ring cowling in the forward position, no increase in cylinder temperatures was obtained. With the narrow ring and exhaust collector ring cowlings the temperatures were somewhat higher, although not high enough to impair the engine performance.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 5, 1930.

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1. Weick, Fred E. : Drag and Cooling with Various Forms of Cowling for a Whirlwind Radial Air-Cooled Engine. N.A.C.A. Technical Report No. 313, Part I, 1929.

2. Weick, Fred E. : Drag and Cooling with Various Forms of Cowling for a Whirlwind Radial Air-Cooled Engine. N.A.C.A. Technical Report No. 314, Part II, 1929.

3. Schey, Oscar W. and Biermann, Arnold E. : The Effect of Cowling on Cylinder Temperatures and Performance of a Wright J-5 Engine. N.A.C.A. Technical Report No. 332, 1929.

4. Wood, Donald H. : Full Scale Wind Tunnel Tests of a Propeller with the Diameter Changed by Cutting off the Blade Tips. N.A.C.A. Technical Report No. , 1930.

5. Diehl, Walter S. and Lesley, E. P. : The Reduction of Airplane Flight Test Data to Standard Atmospheric Conditions. N.A.C.A. Technical Report No. 216, 1925.

TABLE I.

Relation of Air Speed to Engine Speed as Obtained with the Service Type Cowling and with Each of Three Ring Cowlings Used over the Service Type in Tests on the XF7C-1 Airplane

	Service cowling	Narrow ring cowling	Wide ring cowling	Exhaust collector ring cowling
Propeller pitch setting	19.5°	19.5°	20.5°	20.5°
r.p.m.	m.p.h.	m.p.h.	m.p.h.	m.p.h.
1500	109.0	110.4	114.5	116.8
1600	118.0	119.3	124.0	126.3
1700	126.8	128.3	133.5	136.0
1800	135.6	137.4	143.0	145.5
1900	144.4	146.6	152.8	155.0
Maximum r.p.m.	1935	1945	1950	2000
Corresponding m.p.h.	147.3	150.8	157.9	165.0

TABLE II.

Cylinder Temperatures ($^{\circ}$F.) as Obtained in Climb and Level Flight with the Service Type Cowling and with Each of Three Ring Cowlings over the Service Type

	Maximum temperatures during full throttle climb for 10 min.				Maximum temperatures during full throttle level flight for 15 min. at about 1500 ft. altitude			
	Service cowling	Narrow ring cowling	Wide ring cowling	Exhaust collector ring cowling	Service cowling	Narrow ring cowling	Wide ring cowling	Exhaust collector ring cowling
Between fins 2 and 3 above base exhaust side of No. 1 cylinder	255	260	260	250	200	270	270	210
Between fins 5 and 6 above base exhaust side of No. 1 cylinder	230	245	240	220	180	245	270	200
Between fins 11 and 12 above base exhaust side of No. 1 cylinder	315	335	285	305	270	355	330	295
Between fins 2 and 3 above rear spark plug on rear of No. 2 cylinder	360	400	350	380	375	410	370	350
Same position on No. 4 cylinder	365	430	400	435	365	475	400	370
Same position on No. 7 cylinder	365	400	370	450	355	465	415	440
Same position on No. 9 cylinder	370	395	355	390	360	430	405	395
Atmospheric temperature at ground at start of flight	76	65	54	66	68	54	78	69

TABLE III.

Climb Data Obtained with XF7C-1 Airplane for Four Cowlings

Cowling	Reading No.	Corrected time min.	Atmospheric temperature °F.	Atmospheric pressure in. Hg	Standard altitude ft.	True air speed m.p.h.	Engine speed r.p.m.
(Service cowling)	1	.48	77	30.30	675	92	1,750
	2	.87	72	29.55	1,225	87	1,770
	3	1.23	68	28.75	1,875	82	1,750
	4	1.68	64	28.10	2,450	89	1,770
	5	2.14	62	27.40	3,100	92	1,770
	6	2.61	59	26.70	3,775	89	1,770
	7	3.20	58	26.05	4,575	87	1,770
	8	3.73	57	25.45	5,250	88	1,780
	9	4.27	56	24.80	6,025	85	1,770
	10	4.74	54	24.35	6,500	87	1,770
	11	5.23	52	23.90	7,000	89	1,780
	12	5.84	52	23.40	7,700	90	1,770
	13	6.24	49	22.95	8,125	82	1,770
	14	6.68	47	22.50	8,600	89	1,770
	15	7.25	46	22.10	9,150	88	1,740
	16	7.83	46	21.70	9,725	88	1,770
	17	8.26	44	21.40	10,050	93	1,770
	18	8.71	42	21.00	10,500	89	1,760
	19	9.27	41	20.60	11,075	92	1,770
	20	9.72	40	20.30	11,425	93	1,760
	21	10.16	37	20.00	11,775	96	1,770
(Narrow ring cowling)	1	.22	58	29.60	325	86	1,790
	2	1.92	55	27.30	2,850	87	1,730
	3	3.33	47	25.40	4,700	86	1,770
	4	4.79	39	23.70	6,500	89	1,750
	5	6.15	32	22.40	7,850	88	1,750
	6	8.36	38	21.10	10,175	89	1,770
	7	9.82	34	20.10	11,425	87	1,760
(Wide ring cowling)	1	.00	57	29.80	0	93	1,760
	2	1.90	57	27.30	2,950	84	1,720
	3	3.79	57	25.45	5,300	89	1,720
	4	5.41	53	23.90	7,100	96	1,720
	5	6.84	47	22.65	8,450	95	1,690
	6	8.23	41	21.55	9,650	90	1,680
	7	9.58	34	20.55	10,750	90	1,690

TABLE III (Cont.)

Climb Data Obtained with XF7C-1 Airplane, for Four Cowlings

Cowling	Reading No.	Corrected time min.	Atmospheric temperature °F.	Atmospheric pressure in. Hg	Standard altitude ft.	True air speed m.p.h.	Engine speed r.p.m.
(Exhaust collector ring cowling)	1	.61	66	29.50	950	99	1,790
	2	1.79	64	27.85	2,775	94	1,770
	3	3.32	58	25.70	5,060	98	1,760
	4	4.74	51	24.00	6,850	99	1,750
	5	6.55	49	22.90	8,400	101	1,760
	6	7.78	44	21.80	9,500	98	1,740
	7	9.10	38	20.70	10,725	100	1,700
	8	10.43	35	20.20	11,300	-	-

Note.- Climbs with service and narrow ring cowlings were made with propeller pitch setting of 19-1/2 degrees at 42-inch radius and those with the wide ring and exhaust collector ring cowling were made with pitch setting of 20-1/2 degrees.

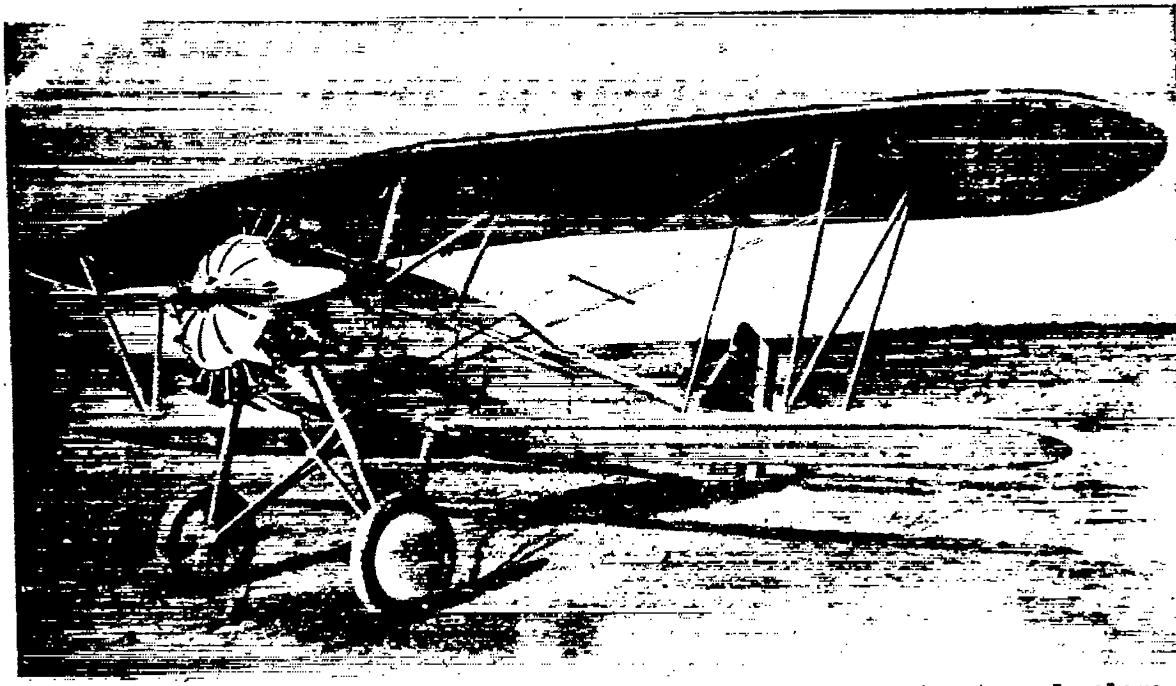

Fig.1 Three-quarter front view of XF7C-1 airplane with service type fuselage and cowling.

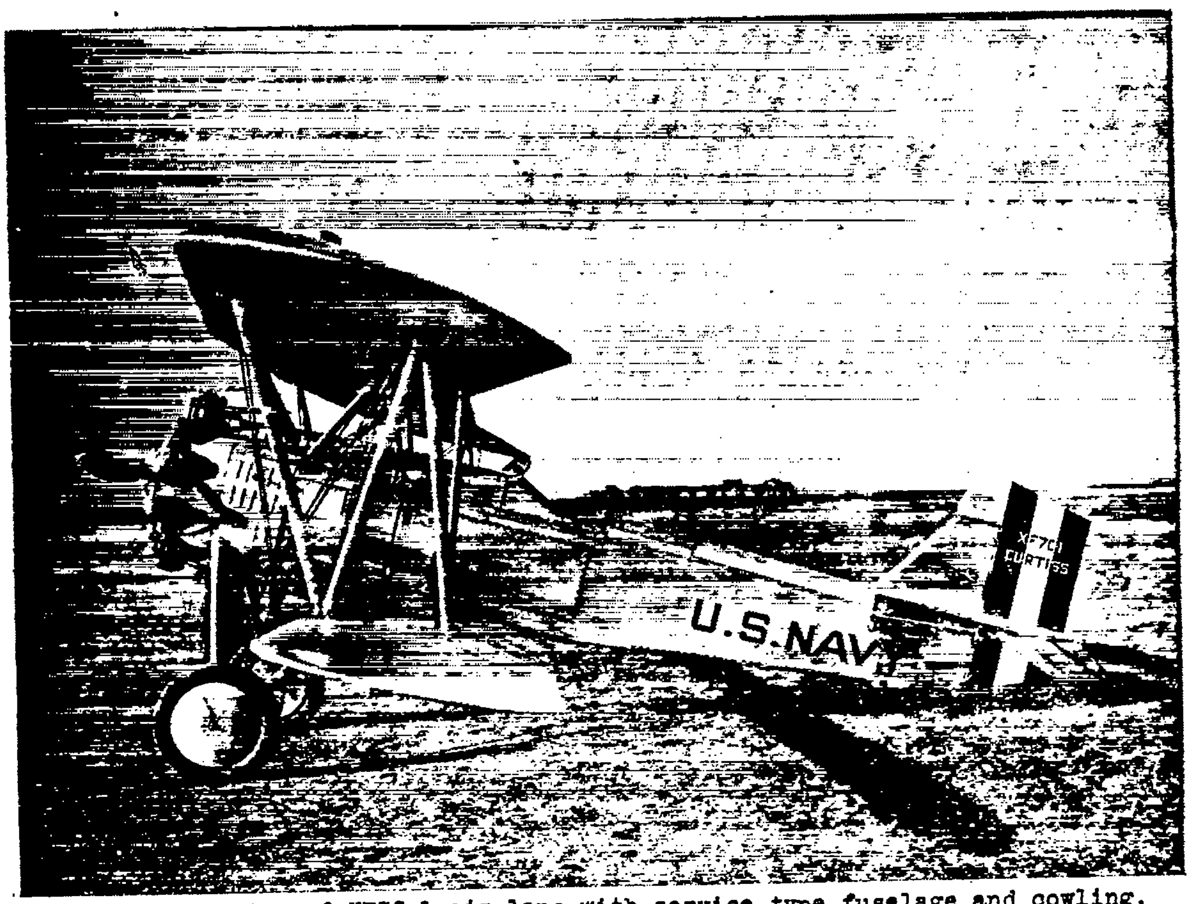

Fig.2 Side view of XF7C-1 airplane with service type fuselage and cowling.

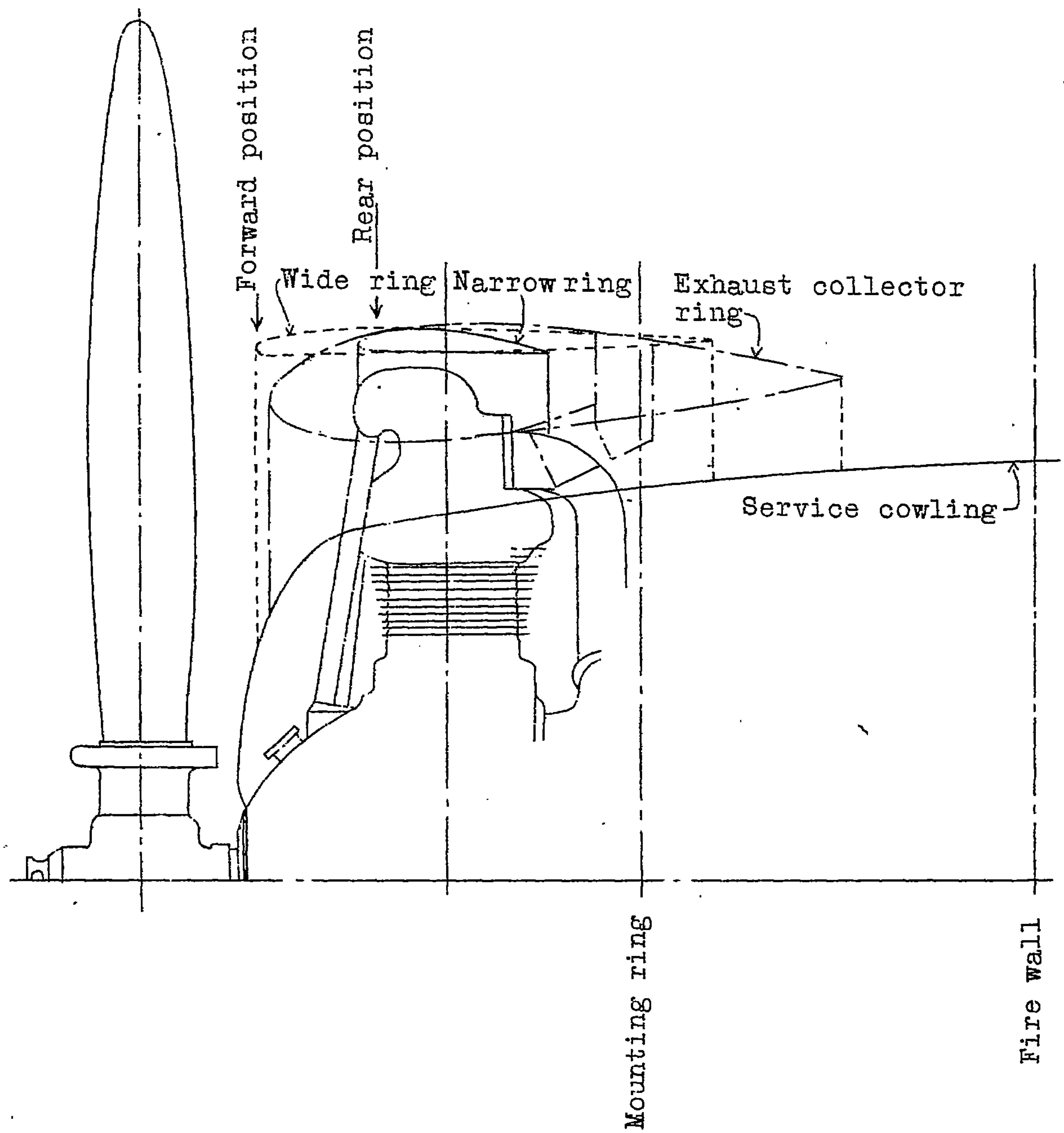

Fig.3 Scale drawing showing cowling sections and location of cowling with respect to center line of cylinders.

Fig. 4

Side view of wide ring cowling as used on XF7C-1 airplane over service type cowling.

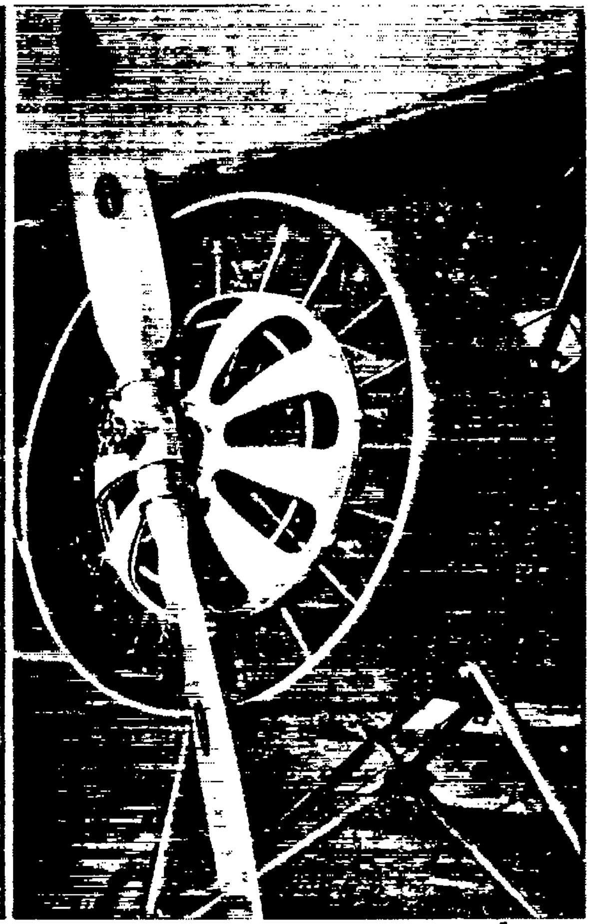

Fig. 5

Three-quarter front view of wide ring cowling as used on XF7C-1 airplane over service type cowling.

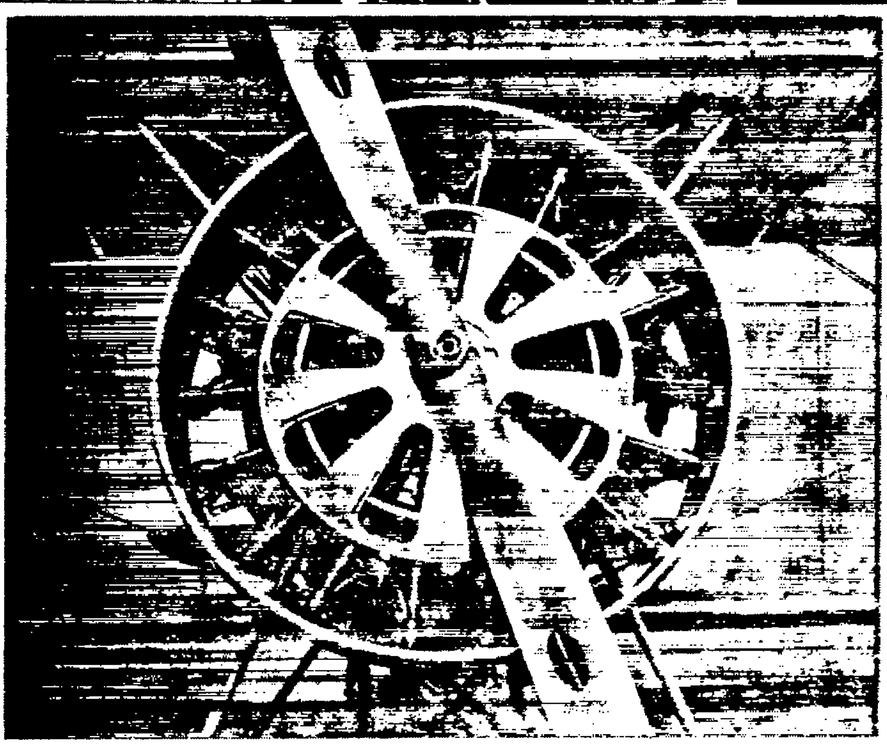

Fig. 6

Front view of wide ring cowling as used on XF7C-1 airplane over service type cowling.

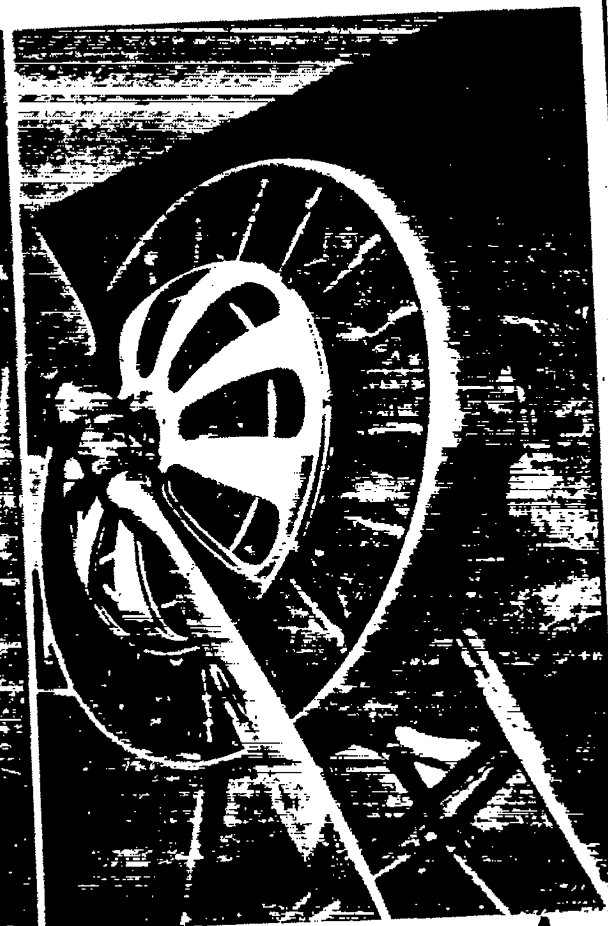

Fig. 7

Side view of narrow ring cowling as used on XF7C-1 airplane over service type cowling.

Fig. 8

Three-quarter front view of narrow ring cowling as used on XF7C-1 airplane over service type cowling.

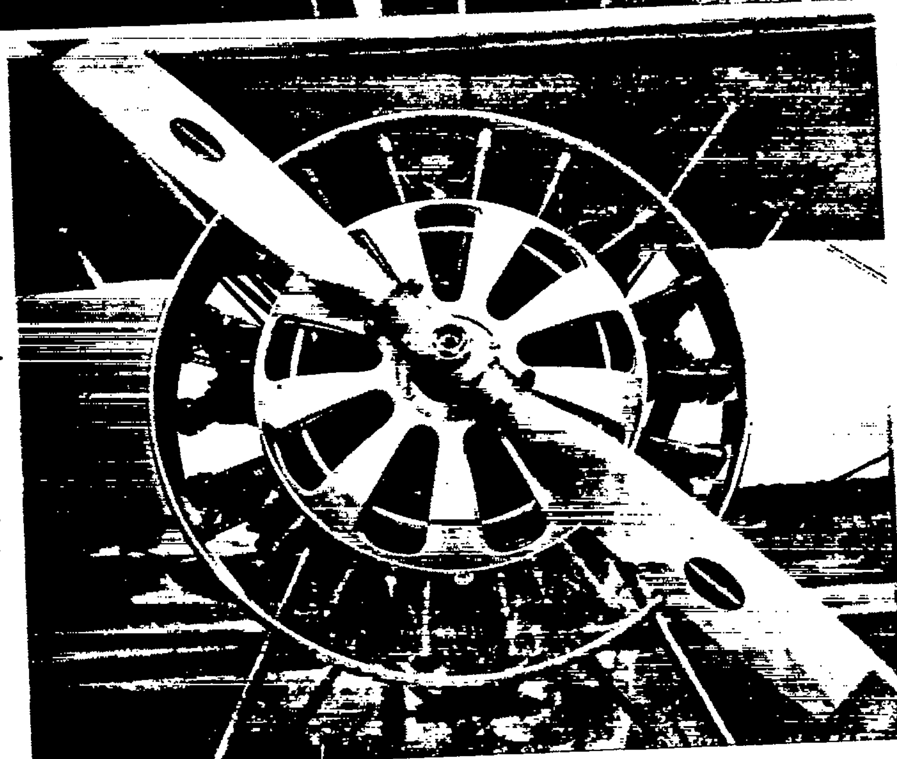

Fig. 9

Front view of narrow ring cowling as used on XF7C-1 airplane over service type cowling.

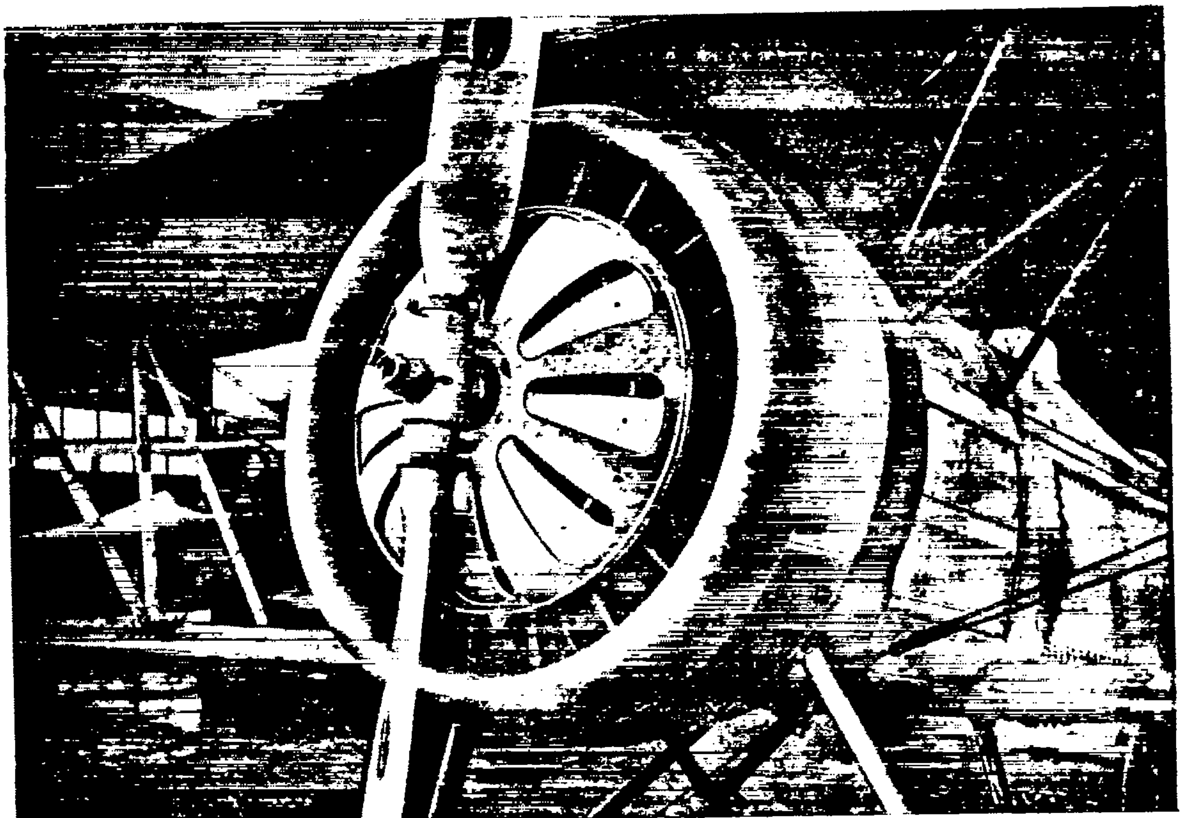

Fig. 11 Three-quarter front view of exhaust collector ring cowling as used on XF7C-1 airplane over service type cowling.

Fig. 10 Side view of exhaust collector ring cowling as used on XF7C-1 airplane over service type cowling.

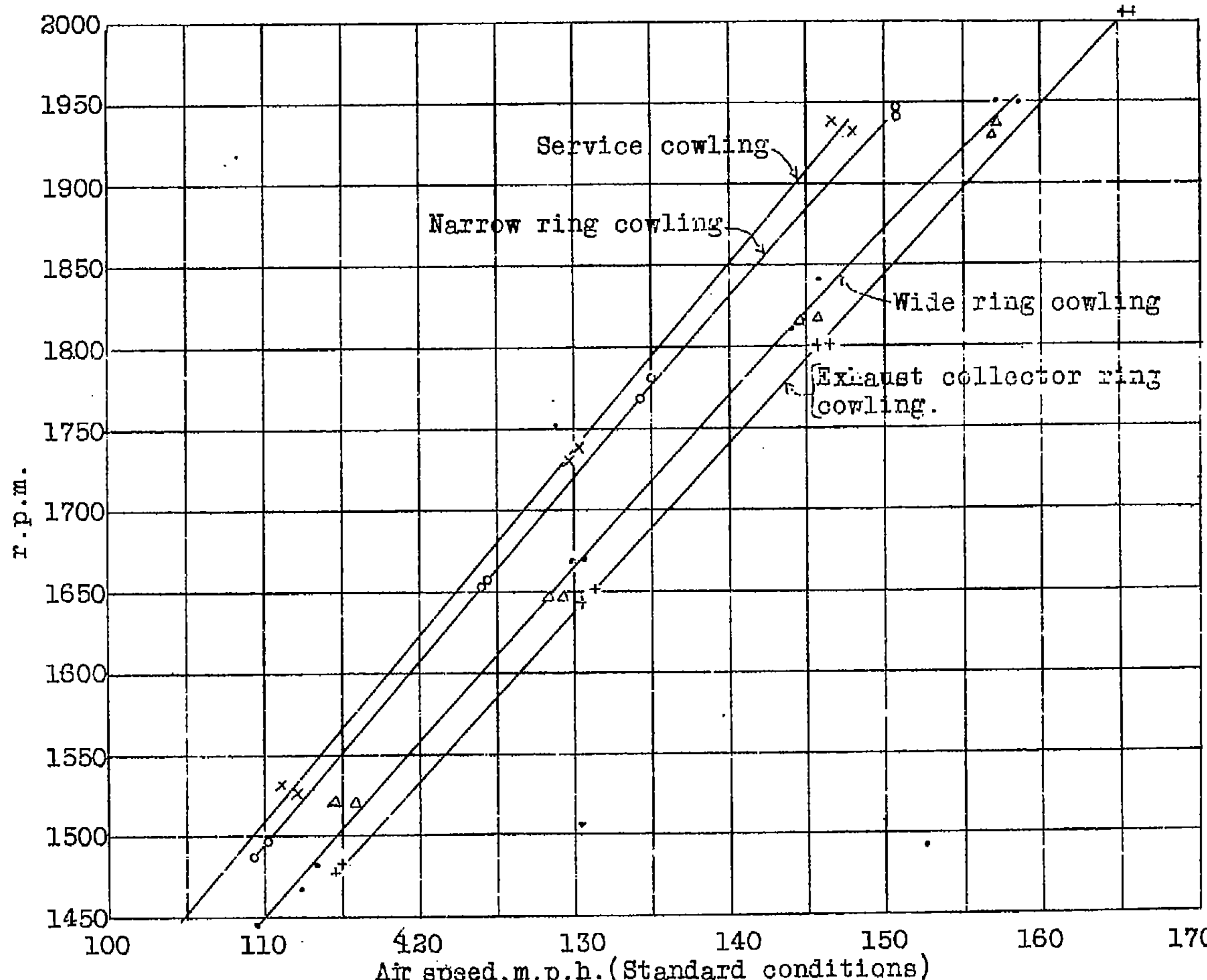

Fig.12 Relation of air speed to engine speed with service type cowling and with each of three ring cowlings as used over service type cowling in tests on XF7C-1 airplane.

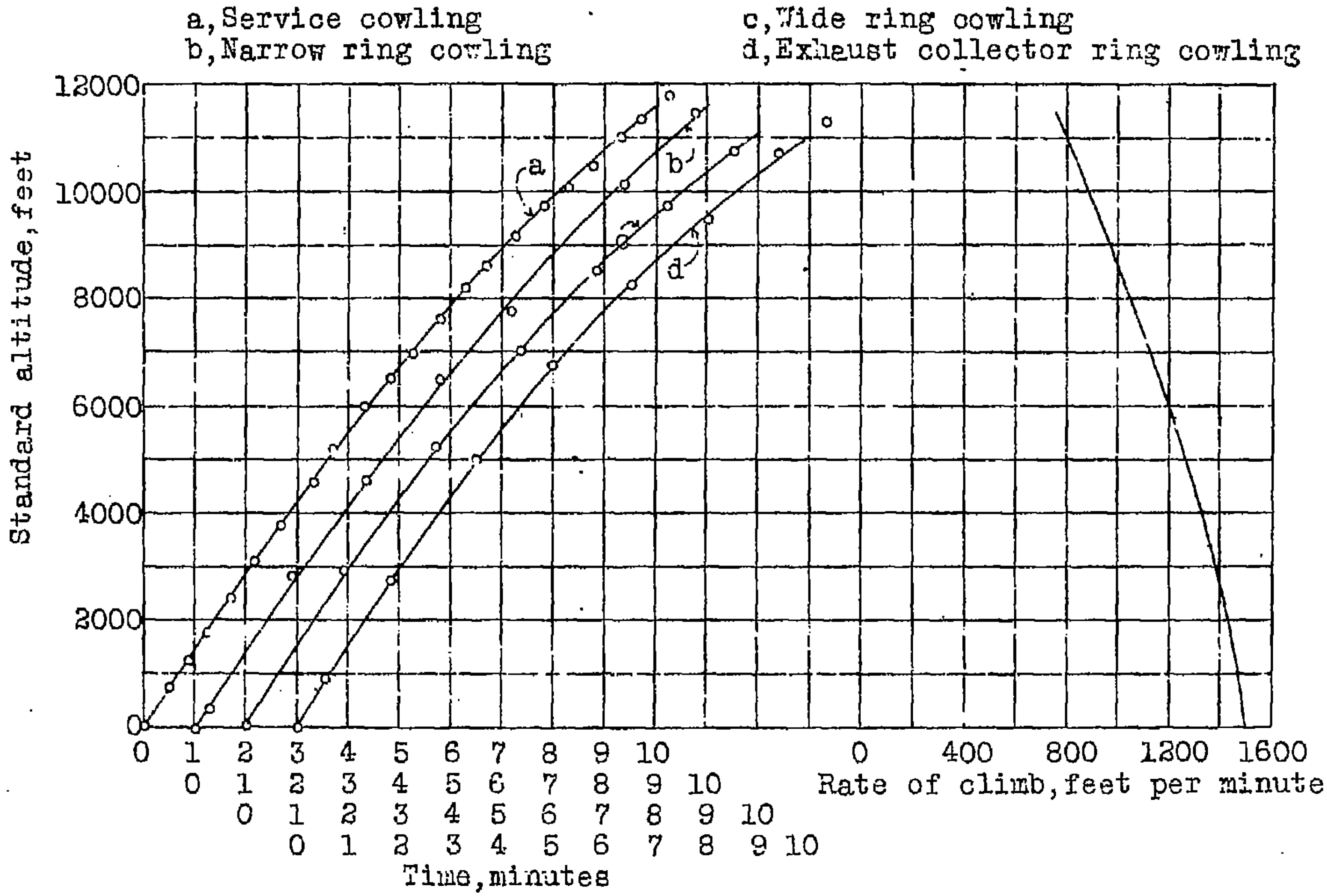

Fig.13 Time-altitude and rate-of-climb curves obtained in tests on XF7C-1 airplane with service type cowling and with each of three ring cowlings as used over service type cowling.

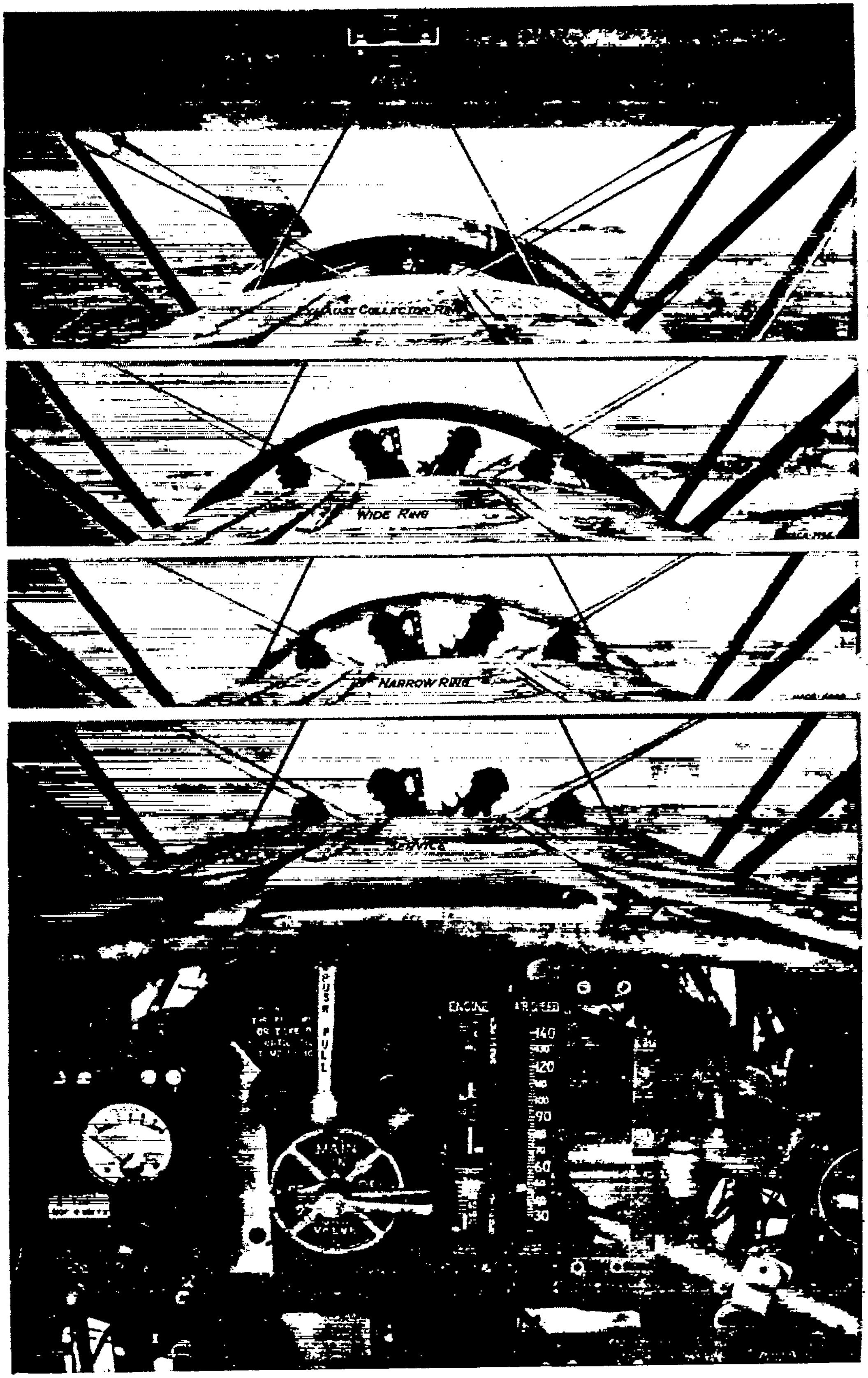

Fig.14 Pilots visibility with service type cowling and with narrow ring, wide ring and exhaust collector ring cowlings over the service type on XF7C-1 airplane in flying position.